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Evaluation of the suitability of two grass species for phytorestauration of contaminated soils from landfills under field and experimental conditions

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ABSTRACT

Many landfills for solid urban waste are located on slopes, terraces and depressions with steep gradients. The cover soil at these sites is affected both by erosive action and by contamination from leachates. In Mediterranean climates, where intense storms frequently occur during spring and summer, the vegetation cover that accompanies the closure of a landfill is very important. This cover can attenuate the interactive processes of erosion and contamination, especially in the surface layer during the first years after closure. The purpose of this study was to evaluate the ability of two native annual ruderal grasses, *Hordeum murinum* and *Bromus hordaceus*, to grow in acidic landfill soils under experimental conditions. In the field, these two species were seen to be among the most frequently occurring members of the *Poaceae* family in urban landfills in the Madrid area. Analysis of plants taken from these landfills revealed that the N content of *B. hordaceus* was greater than *H. murinum*, while the K content was lower. Concentrations of other elements examined (P, Ca, Mg, and Na) were approximately the same in both species. The values of soil parameters analysed (pH in water, conductivity, organic matter, N, NH_4^+, available P, Cl^-, $SO_4^=$, NO_3, Ca, Mg, K and Na) were also approximately the same for both species. In the experimental phase, grass seeds taken from the study area were grown in pots containing soil from the same area, which were treated with leachates from area landfills. We analysed the impact of this treatment on soil composition, plant growth (estimated by number of leaves and dry weight) and nutritional responses of both species. In the soil, the leachate treatment had the greatest impact on pH, conductivity, Mg, Na, Cl^-, and $SO_4^=$. Analysis of the two grass species, however, revealed that in *H. murinum* only Na content increased significantly, while in *B. hordaceus* the changes were much less pronounced. In both cases, leachate treatment had a positive impact on plant growth. These results highlight the ability of both species to flourish in recently sealed landfills.

Key Words: soil pollution, plant composition, plant growth

INTRODUCTION

The contamination in superficial soil layers, the level at which most soil-plant interactions occur, is of great interest in ecotoxicology. Landfills interfere with the natural occurrence and cycling of elements, increasing elemental fluxes within primary and secondary processes by generally altering the availability of nutrients and sometimes by reducing the potential productivity of the soil. Soil salinity and a higher local content of some trace elements are the most significant aspects related to pollution problems from landfills in semiarid environments (Pastor et al., 1993b; Hernández et al., 1998)

A great deal of work has been done to develop and identify plants that can resist the problems of mineral imbalance caused by soil pollution in order to ascertain the differential responses to mineral elements. Researchers have, above all, tried to understand the physiological and chemical differences in plant responses to several elements and to explain plant ability to survive with low levels of these nutrients or to tolerate high levels.

This paper aims to present the response of two native herbaceous species in mixed urban and industrial waste polluted soils.

The study species (*Hordeum murinum* and *Bromus hordaceus*) were chosen in view of their natural frequency in the plant cover of landfills. *B. hordaceus*, which has some food value for sheep and some wild animal species, and *H. murinum*, a representative ruderal species in this environment, were chosen for their importance in recovering degraded soils, where they are used as starting material in landfill revegetation (Pastor et al., 1993d).

The entire study falls within the field of plant ecology and mineral nutrition of the abovementioned native species, which can grow in sealed landfills with both acid and basic soils and which may serve to initiate the biological recovery of these environments, as well as minimize the serious erosion problems that occur there. In previous studies, we dealt with some aspects related to this question (Pastor et al., 1993a,c; Adarve et al., 1999). Here we basically focus on the composition of these species when they grow on landfill soils and in other degraded systems surrounding landfills. We will also study the main soil characteristics of the rooting horizon layer of this type of soil in order subsequently to analyze the response of plant composition to various soil variables.

Another aspect of the study was carried out under controlled environmental conditions. A landfill leachate was tested for its effects on an acidic soil and both grass species. In a second phase, the experiment was repeated with a higher leachate concentration and with plants grown on contaminated soil from the previous experiment. The purpose of these assays was an attempt not only to evaluate the effects of some chemical landfill leachates on the soils and plant chemistry, but also to test the capacity of the aforementioned species to grow on contaminated soil. Thus, the effect of the leachates was measured against the chemical characteristics of the soils and mineral composition in the plant species. Some visible effects on vegetative plant growth were also examined during the course of the experiment and at harvest. The plant growth parameters observed were the number of leaves and dry weight at harvest.

MATERIALS AND METHODS

Chemical analyses of soils, plants and leachates

The chemical parameters analyzed in the soils, plants and leachates were those that constitute indicator elements of contamination by leachates.

53 samples of *Hordeum murinum* and 50 of *Bromus hordaceous* from landfills on acid and basic substrates from the centre of the Peninsula were analysed, together with the corresponding soils. The ecology of mineral nutrition was studied through the correlation of 23 soil variables and those of plant mineral composition.

The soils, plants and leachates were analyzed following the official Spanish methods M.A.P.A., 1982. The analytical procedures for soils and plants were those described by Hernández and Pastor, 1989. The anion concentrations of Cl^-, $SO^=_4$, NO^-_3, F^- and $PO^=_4$ in the leachates and soils were analyzed by ion chromatography with a Dionex Model 10 chromatograph using an AGHA precolum, an AS4A separator column, and an AHMS suppresser column connected to a recorder and a Hewlett-Packard 3390 A integrator. $CO^=_3$ and HCO^-_3 were determined by titration techniques. The Ca^{++}, K^+, and Na^+ concentrations in the leachates, soils and plants were determined by flame photometry and those of Mg^{++}, Fe^{++}, Cu^{++}, Mn^{++}, Zn^{++} and B^{+++} by atomic absorption spectroscopy. NH^+_4 and P were determined by colorimetric techniques, the chemical oxygen demand by permanganate oxidation capacity, total-N by the Kjeldahl nitrogen method with an autoanalyzer and organic matter by oxidation with potassium dịchromat and concentrated sulphuric acid.

Experimental design and mathematical analysis

After being collected from ruderal grasslands in the above mentioned area, the seeds were germinated for one week with permanently saturated filter paper inside Petri dishes and in darkness at about 25ºC. After one week the seedlings were sown in the pots. The leachate treatments were initiated with 15-day-old seedlings.

The natural leachates applied to the soil and plants in the experiment were collected from two piezometers prepared in a subterranean discharge area at the foot of a sealed landfill. At each phase of the experiment the total volume was collected on the same day and kept in storage at 4ºC. These leachates represented a natural mixture of landfill leachates and groundwater. The soil used in the experiment was an Alfisol with a pH 5.3 representative of the Madrid area, developed on an arkosic substrate. It has a sandy loam texture. The chemical composition of the soil will be presented later as «initial soil".

The experiment consisted of two phases. The plants were grown in a greenhouse. The control plants not exposed to leachates were watered with 50 ml/day of deionized water, while those exposed to leachates received a similar quantity of natural landfill leachates.

In the first phase of the experiment, therefore, a total of 16 pots were filled with the soil collected in the study area and sieved through a < 2mm mesh screen. Five seedlings (germinated in Petri dishes) were subsequently sown in every pot, there being eight pots per species. As part of the watering supply, the leachates were applied to four of the eight pots of each species, while the other four pots (the controls) received an equivalent amount of mili-Ro water (50 ml/day). All the pots contained 3 kg of soil.

In the second phase of the experiment, a higher leachate concentration was used as well as seedlings grown in contaminated soils of the previous phase. The plants were planted in the soil of their respective species from Phase I. Thus, three seedlings per pot were sown in six pots with approximately 1.5 kg of soil. Three pots were watered again with leachates, while the other three were the controls (watered with mili-Ro water). The total number of pots in Phase II was 12.

The leachate effects were measured against the chemical characteristics of the soils, dry weight and mineral composition of the aerial part of plants i.e. in flower at the beginning of the fruit phenological stage. In addition, the plants were checked for leaf damage when they were seven weeks old and at harvest. The dry weight of each individual plant was determined. The chemical analyses were performed on the plants from each pot. The five plants per pot (in Phase I) and the three plants per pot (in Phase II) were mixed for chemical analysis. This produced four and three plant samples in Phase I and II, respectively, for each species grown and watered with each treatment. As regards soil samples, the corresponding samples of soil and treatment were analyzed.

For the mathematical analyses, most of the variables were transformed by applying the log x+1. Correlation analysis and several factorial analyses of variance (ANOVA) were carried out with chemical variables from soils and plants. The BMDP Statistical Software computer package was used (BMDP, 1992).

RESULTS AND DISCUSSION

Chemical composition of the samples from the landfill and humanised surrounding area

Table 1 shows the average values and typical deviations of the different chemical soil parameters in the soils in which the two study poaceae grew.

Table 1. Average values for the soil parameters in the soils of the landfill areas and their neighbour soils, where *Hordeum murinum* and *Bromus hordaceus* grow

Soil Parameters	Acid Soils		Basic Soils	
	H.murinum	*B.hordaceus*	*H.murinum*	*B.hordaceus*
pH	5.8±1.0	5.8±1.0	7.4±0.2	7.3±0.2
Conductivity	2.6±3.6	2.6±3.5	3.6±5.2	3.9±5.5
O. M.	2.2±2.3	2.4±2.4	4.5±3.2	4.4±3.4
N	0.124±0.124	0.132±0.127	0.249±0.179	0.240±0.189
P (assimil.)	8.8±6.2	8.4±6.2	32.1±32.6	28.0±28.6
Cl	41.7±40.5	40.1±40.1	50.7±96.5	57.0±101.8
SO4	18.0±27.7	17.4±27.2	112.0±189.2	114.3±195.0
NO3	8.3±9.5	9.8±11.7	21.4±66.4	22.3±70.1
NH4	1.8±1.0	1.8±1.0	1.6±1.5	1.6±1.6
Ca	149.3±82.5	153.0±82.3	609.4±303.6	593.9±310.1
Mg	16.1±10.8	16.4±10.7	57.7±56.9	62.6±59.3
K	29.5±27.3	28.8±26.9	53.9±44.2	50.0±45.6
Na	16.5±40.1	16.2±39.2	32.6±72.6	37.0±76.8
B	0.01±0.03	0.01±0.03	0.47±0.57	0.48±0.61
Zn	1.6±2.4	1.5±2.3	19.5±41.6	20.6±44.4
n	21	22	32	28

In acid soils the average values were similar for both species, while in basic soils greater differences existed between the preferences both species presented. Thus, *H. murinum* grows on soils with more phosphate, Ca^{++} and K^{+} and a lower level of Cl^{-} and Na^{+} than *B. hordaceus*. There are also clear differences in the average values attained by soil parameters in acid and basic soils when we compare them for each species. The greatest differences correspond in the first place to the exchangeable Ca^{++} followed by exchangeable Mg^{++}, K^{+} and Na^{+}. The greatest difference among the anions is in the sulphates. However, there are also appreciable differences in chlorides and nitrates. Among the oligoelements the difference was seen in Zn^{++}. The differences in pH and conductivity are equally noteworthy.

The composition of both poaceae growing on the study soils is shown in Table 2. The N, Ca^{++}, Mg^{++}, Mn^{++}, Fe^{++} and Zn^{++} contents are less in *H. murinum*; on the other hand, the greater concentration of K is worth noting. For B^{+++} and Cu^{++}, *H. murinum* takes up less than *B. hordaceus* in acid soils, while on basic soils it takes more.

Table 2. Average values for nutrients analysed in *Hordeum murinum* and *Bromus hordaceus* plants from landfills and the neighbour soils

Chemical Parameters	**Acid Soils**		**Basic Soils**	
	H.murinum	*B.hordaceus*	*H.murinum*	*B.hordaceus*
N	1.36±0.31	1.46±0.42	1.22±0.34	1.27±0.32
P	0.25±0.08	0.24±0.09	0.20±0.05	0.22±0.06
K	1.29±0.48	0.99±0.46	1.23±0.46	0.94±0.28
Ca	0.33±0.08	0.39±0.26	0.34±0.11	0.37±0.12
Mg	0.11±0.02	0.12±0.06	0.13±0.04	0.16±0.06
Na	0.12±0.17	0.10±0.13	0.07±0.08	0.05±0.10
Mn	77.1±57.5	110.2±96.4	36.4±18.5	63.9±32.8
Fe	535.2±411.2	679.0±588.2	376.6±240.2	545.9±928.9
Zn	68.3±23.4	79.4±40.5	64.7±33.7	64.0±46.0
B	8.1±6.3	9.0±9.0	21.6±64.1	17.5±22.0
Cu	0.0±0.0	2.3±7.5	0.63±3.54	0.0±0.0
n	21	22	32	28

Table 3 displays the significant coefficients of correlation among the parameters studied for *H. murinum* and *B. hordaceus* and 23 soil variables. As regards the influence of contamination on the soils, we may conclude that N at high pH is not readily absorbed due to high levels of B^{+++} in the soil, which seem to affect the nitrogenous nutrition of *B. hordaceus.* The Ca^{++} in *Hordeum murinum* can also be seen to be positively correlated with the level of chlorides in the soil. They are probably calcium chlorides, and this species appears to withstand large concentrations of these salts. The same does not occur in the other study species. However, when *B. hordaceus* grows on soils with a higher degree of saturation in bases, Ca^{++} absorption is also promoted. This affirmation rests on the positive correlation of these two parameters for *B. hordaceus.*

In the case of *H. murinum*, Ca^{++}, Mg^{+} and P levels in the soils' exchange complex are positively correlated with the Mg^{++} in the plant. Neither do high levels of B^{+++} and Zn^{++} in the soil appear to affect the nutrition of this element. Thus, in saline environments, such as the urban landfill discharge areas, this species takes up Mg^{++} well, probably due to the salts that free it in soil exchangeable solution with a very high phreatic water level. However, the negative correlation between this nutrient and the degree of saturation in bases (V%), significant to over 95% for *Hordeum murinum*, indicates that good conductivity is needed in soils for the Mg^{++} to be made available (See apropos the correlations in the table between the variables in question). When Na^{+} content in the soil is high, there is a lower level of K^{+} in the *H murinum* plants.

Table 3. Linear correlation between mineral composition of the two species and soil parameters

	N	P	Ca	Mg	K	B	Zn	Fe	Mn	Cu
H.murin										
Sand		0.371**						0.296*	0.331*	
Silt		-0.275*		0.270F						
Clay							-0.455***	-0.329*	-0.401**	
Field c.		-0.302*				0.369**			-0.290*	
Wilt.p.	0.280*	-0.283*				0.360**				
Avail.w		-0.309*				0.279*		-0.288*	-0.326*	
pH	-0.275*	-0.304*							-0.483***	
Cond				0.408**	-0.231F		0.447***	0.343*	0.399**	0.234F
O.M.		-0.308*				0.427**				0.252F
N						0.383**				0.322*
P				0.318*				-0.255F	-0.440**	0.279*
Cl			0.291*		-0.231F		0.372**	0.257F	0.398**	0.233F
SO4				0.607*			0.451***			0.309*
NO3		-0.233F							0.277*	
Ca	-0.253F	-0.315*		0.318*				-0.270F	-0.420**	
Mg	-0.303*	-0.274*		0.484**		0.301*			-0.240F	0.325*
Na				0.364**	-0.315*	0.281*	0.394**	0.455***	0.410**	
K		-0.370*				0.334*				
NH4	0.259F							0.301*	0.394**	
B	-0.231F	-0.233F		0.546***		0.267F				0.291*
Zn				0.422**		0.361**	0.606***			0.293*
S	-0.250 F	-0.344*		0.336*					-0.303*	
V				-0.320*		-0.307*	-0.549***		-0.300*	
B.horda										
Sand										
Silt				0.395**		0.260F				
Clay					0.255F		-0.418**		-0.291*	-0.291*
Field c.										
Wilt.p.		-0.252F		0.316*						
Avail.w				0.294*						
pH				0.278*					-0.370**	
Cond		-0.240F		0.410**	-0.242F	0.267F	0.307*		0.327*	
O.M.		-0.303*		0.294*			0.296*			
N		-0.259F		0.235F						
P								-0.238F	-0.336*	-0.289*
Cl							0.373**		0.274*	
SO4				0.312*		0.313*	0.306*			
NO3		-0.269F	0.242F	0.308*					0.373**	
Ca				0.386**					-0.232F	-0.231F
Mg	-0.323*			0.513***		0.364**				
Na		-0.261F		0.463***		0.386**	0.330*	0.315*	0.392**	
K		-0.430**		0.281*						
NH4									0.288*	
B	-0.272*			0.395**		0.468***				
Zn						0.318*	0.427**			
S	-0.251F	-0.236F		0.432**		0.260F				-0.230F
V			0.318*			-0.269F	-0.266F			

In the light of the correlations between trace elements and soil moisture parameters, we can state that waterlogging of the surface layer may promote the availability and absorption of Zn^{++}, Cu^{++}, Mn^{++} and Fe^{++}. These results agree with those of Bjerre and Schierup (1985). Bearing this in mind attention needs to be paid to the possible toxicity of these elements for plants in discharge areas of landfills with a high phreatic level, and also to those soils in which for climatic (rainfall) or geomorphological (slope) reasons, surface leachates occur.

Chemical composition of the leachates

Table 4 indicates the leachates'chemical properties. The pH of the leachates ranged from neutral to basic. They were rich in Cl^-, $SO^=_4$, HCO^-_3, Na^+ and Mg^{++}, but low in NO^-_3, $CO^=_3$, $PO^=_4$ and trace elements, except for B^{+++} content. The high concentrations of some ions in leachates are also very important because of the possible salinity increase in the soils. Na content is interesting for its important contribution to salinity in urban landfill soils. It is noteworthy that Na concentration in leachates was the highest among all the cations analysed._

The leachate concentrations used came within the range of the levels most frequently reported in the literature. The pH and C.O.D. values corresponded to the methanogenic decomposition phase of the wastes (Stegman, 1982; Kmet et McGinley, 1972). This was in accordance with the age of the sealed landfills where the leachates were collected.

Effect of leachates in soils

Table 5 presents the chemical composition of the soil before any treatment and after the treatment with deionized water or landfill leachates in both experimental phases. The F values and their statistical degree of significance established by ANOVA performed with one grouping factor (treatment) are also shown.

The table shows that in both phases of the experiments, the qualitative chemical changes in the soil with the leachate treatment are very similar compared with those of the control soil. The pH values, conductivity and the Cl^-, $SO^=_4$, Mg^{++} and Na^+ concentrations increased significantly in the soil watered with leachates in both phases in accordance with the high level of these parameters in the leachates. Conductivity and pH values were noticeably higher in soil watered with leachate in Phase II than in the soil previously contaminated by leachate in Phase 1. The available-P and B-concentrations also increased, with highly significant ($p<0.01$) and very highly significant ($p<0.001$) F values, respectively, in the soils treated with leachates in Phase II. An increase in conductivity, Cl^- and $SO^=_4$, as well as a high content of Na^+, B^{+++} and, to a lesser degree, of Mg^{++} had also been observed in studies about soils affected by landfills in field conditions (Pastor et al.,1993-b; Hernández et al., 1998). On the other hand, O.M., N, NH^+_4, Ca^{++} and K^+ concentrations in soils watered with leachates remained very similar or varied only slightly

Table 4. Chemical analysis of the leachates used in the experiment and typical leachate levels reported in literature

	Leachate Parameters	PhaseI of the experiment	PhaseII of the experiment	Leachate levels in literature(a)
	pH		7.6	8.3 3.7-8.5
Conductivity	(µS/cm)	1400	5450	3000-15000
C.O.D.	(mg/l)	15.5	100.0	60-1268
T.S.D.	(mg/l)	4302	5339	3000-20000
Total hardness	(°F)	185	161	100-1337
Cl-	(mg/1)	198	1170	5-4350
SO=4	(mg/1)	1175	1022	0-84000
NO-3	(mg/1)	7	0	0-10
CO3	(mg/1)	0	12	-
HCO3	(mg/1)	1831	1500	-
PO4	(mg/1)	0	0	0-50
F-	(mg/1)	3.7	0.0	-
Ca++	(mg/1)	108	148	5-7000
Mg++	(mg/l)	452	355	12-15000
Na+	(mg/1)	470	1025	0-8000
K+	(mg/1)	56	31	2-4000
NH4 +	(mg/1)	-	2.5	0-1000
Fe++	(mg/1)	<0.01	<0.01	0-5000
Cu++	(mg/1)	<0.01	<0.01	0-10
Zn++	(mg/1)	<0.01	0.03	0-1000
B+++	(mg/l)	0.84	72.50	1-70
Mn++	(mg/1)	-	0.6	0-1500

(-) undetermined; (a) Clark and Piskin, 1977; Kmet and McGinley, 1982; Sridharan and Didier, 1988; Lozidou and Kapetanios, 1991.

compared with their respective control soils in both phases of the experiment, while NO_3^- decreased in Phase I and increased in Phase II, but not significantly in either. Watering with deionized water in the second phase of the experiment also caused an increase of conductivity, $SO_4^{=}$, and NO_3^- levels. Cl^- decreased a little and Ca^+, Mg^{++}, K^+, Na^+, O.M., N, NH_4^+ and P_2O_5 were slightly lower than, or the same as, the soils treated with leachates in the first phase.

The salinity of the soils contaminated by leachates from landfills may have a negative effect in semi-arid areas where salinity problems are not uncommon. According to Lal et al. (1989), the salts which most frequently accumulate include Cl^-, $SO_4^{=}$, Na^+, Mg^{++} and Ca^{++}. The Na^+ concentration was the cation that increased most in both phases of the experiment. In the second phase, the B^{+++} content was also high in the soils previously treated in Phase I. This micronutrient may be toxic for plants because the pH values of both types of soil aid its availability (Kabata-Pendias & Pendias, 1984). In the second phase, the Cl^-, $SO_4^=$ and NO_3^- levels were too high for the plants (Abilio-Abundo, 1981). According to the latter, the N and cation content in the second phase were also high. The soils contaminated by leachates from the landfill also implied ecotoxicological effects on the plants (Pastor, et al., 1993-e; McBride et al., 1979). In addition, the contaminants remain in the soil much longer than in other components of the biosphere, and pollution of the soil, especially from heavy metal, appears to be virtually permanent (Kabata-Pendias et Pendias, 1984).

The modifications of the chemical soil content by leachates with regard to the accumulation of chemical substances (the increase of the ion content and heavy metals) may be accompanied not only by a decrease in soil quality, but also by a disturbance of soil plant cover and by bioaccumulation of contaminants in plants. As a result, it is possible that the pollution reaches the food chain. The toxicity and persistence of some of the substances from leachates aggravate the magnitude of the problem.

Response of the plant species

Table 6 shows the mineral content of *Hordeum murinum* and *Bromus hordaceus* grown on the soil treated with deionized water or leachate in both phases of the experiment. This table also presents the average number of leaves per individual plant after seven weeks and the dry weight average per individual plant at harvest. It also displays the F values and their statistical degree of significance from ANOVA.

It can be observed that in both the non-contaminated and contaminated soils, *Hordeum murinum* was more frugal than *Bromus hordaceus,* considering its Ca^{++}, Mg^{++}, Na^+ and B^{+++} requirements, while *H. murinum* was more demanding with regard to K^+. The significant increase in Na^+ and B^{+++} content in both grasses with the leachate treatments in Phase II was the most outstanding effect. The B- content in the plants treated with leachates reached levels of between 600 and 4000 ppm, which may justify the disturbance to which the plants were subjected in these conditions. In soil, B^{+++} is considered the most mobile element among the micronutrients. Besides, in soils of arid and semi-arid regions, it is likely to concentrate in the surface horizons (Kabata-Pendias et Pendias, 1984). Alikhanova (1980) observed B^{+++} toxicity between 283 to 333 ppm in cotton, and Davis et al.(1978) stated that 80 ppm B^{+++} is toxic for barley seedlings.

On the other hand, in the majority of the results obtained, the increase in Na^+ content brings about a decrease in K^+, especially when the increase in Na^+ appears to be higher for the species (Phase II). In both phases of the experiment, a notable decrease in K^+/Na^+ ratios was observed in both species with the leachate treatment when compared with the K^+/Na^+ ratios of those treated with deionized water. The lower K^+ content may be explained as a consequence of the well-known antagonism between these monovalent cations. The same effect has been observed in barley (Benes, et al. 1996) and maize (Izzo et al., 1993).

Table 5. Chemical analysis and F values with their statistical degree of significance from ANOVA of the initial soil and soil watered with deionized water and landfill leachates in the two experimental phases

Soil Parameters		Initial Soil	Soils with Deionized Water	Soils with Leachates	F
PHASE I					
pH		5.5	5.5±0.0	5.8±0.1	10.0*
Conductivity	(µS/cm)	113	94±6	590±45	121.80***
Organic matter	(%)	1.6	1.1±0	1.0±0.16	1.73
N	(%)	0.06	0.06±0.00	0.05±0.00	9.00*
NH_4^+	(mg/100g)	1.4	1.5±0.4	1.0±0.1	1.56
Available-P	(mg/100g)	12.5	12.0±0.4	13.8±0.7	5.44
Cl^-	(mg/100g)	1.2	0.6±0.0	10.0±0.9	109.21 ***
$SO_4^=$	(mg/100g)	5.2	2.4±0.2	43.3±2.2	339.46***
NO_3^-	(mg/100g)	9.4	7.3±1.8	4.3±1.1	1.97
Ca^{++}	(mg/100g)	45.0	136.3±1.3	138.3±3.5	0.29
Mg^{++}	(mg/100g)	18.8	17.2±0.1	31.0±1.1	167.05***
K^+	(mg/100g)	16.5	16.3±1.2	17.5±1.0	0.00
Na^+	(mg/100g)	1.5	1.6±0.1	21.9±1.1	320.05***
B^{+++}	(mg/100g)	0.0	0±0	0±0	0.00
PHASE II(a)					
pH		5.8±0.1	6.3±0.1	7.0±0.1	31.94**
Conductivity	(µS/cm)	590±45	2200±268	7375±636	56.31***
Organic matter	(%)	1.0±0.16	1.0±0.1	1.1±0.1	0.27
N	(%)	0.05±0.00	0.05±0.00	0.07±0.02	1.46
NH_4^+	(mg/100g)	1.0±0.1	0.4±0.2	0.2±0.2	0.18
Available-P	(mg/100g)	13.8±0.7	10.9±0.3	13.0±0.2	32.11**
Cl^-	(mg/100g)	10.0±0.9	6.3±1.6	53.3±2.6	247.96***
$SO_4^=$	(mg/100g)	43.3±2.2	52.0±6.4	101.0±16.0	8.19*
NO_3^-	(mg/100g)	4.3±1.1	4.3±3.7	18.0±1.9	0.82
Ca^{++}	(mg/100g)	138.3±3.5	123.8±4.7	141.3±50.5	5.76
Mg^{++}	(mg/100g)	31.0±1.1	31.3±1.3	42.5±1.4	74.71**
K^+	(mg/100g)	17.5±1.0	12.3±1.4	16.0±1.8	2.61
Na^+	(mg/100g)	21.9±1.1	18.5±0.9	80.0±4.6	175.24***
B^{+++}	(mg/100g)	0±0	0.1±0.02	3.6±0.2	254.54***

(a) Soils watered with leachates in Phase I and used again in Phase II. *$P< 0.05$: (F at 95%: significant); **$p<0.01$: (F at 99%: highly significant); ***$p<0.001$ (F at 99.9%: very highly significant).

Table 6 also includes the dry weight quotient of the plants with the leachate treatment and of the plants with the deionized water treatment. It will be used below to comment on the effects of leachates on plant growth. The relative dry weight of plants in solid urban waste conditions divided by that of the control plants had previously been used as a toxicity index by García and Díaz-Marcote (1992).

As regards species'dry weight, watering with leachates generally had a fertilizing effect because of the weight increase with the leachate supply in *Hordeum murinum*, while *Bromus hordaceus* in Phase II underwent a 30% drop in dry weight. No leaf damage whatsoever was observed in either grass species in the course of the experiment or at harvest.

In view of the results, the increase in Na^{+} and B^{+++} concentrations from leachate watering was the most clearly reflected change in the content of these elements in the species tested. Consequently, the B^{+++} content in the plants with leachates is the greatest threat because of its potential accumulation in the plants tested and, therefore, its potential toxicity and transfer to the food chain in view of the high levels observed in plant tissue. Thus, special attention must be given to this trace element in areas affected by landfill leachates. In general, most trace elements, including B^{+++}, are more readily available with soil acidity (Kabata-Pendias et Pendias, 1984; Brieger et al.., 1992; Hooda, 1997).

The soil salinity increase observed in the soils with the leachate treatments may also explain the dry weight reduction in the plants (Benes et al., 1996; Izzo et al., 1993; Devitt et al., 1993), especially in Phase II, in which conductivity values were 7375µS cm^{-1} i.e. very near the threshold tolerance level established by plant ecologists (7 mS cm^{-1}) (Le Houérou, 1993).

CONCLUSIONS

It may be concluded that the chemical composition of the soil and the plant content of the species were affected by leachate supply. The species tested responded differently to soil contamination. Leachate contamination significantly increased conductivity and Cl^{-}, $SO_4^{=}$, Mg^{++}, Na^{+} and B^{+++} concentrations in the soil in accordance with the high level of these elements in leachates. Electric conductivity increased drastically (to near the threshold tolerance level established by plant ecologists) in the soil after a second leachate watering (Phase II). Watering with leachates in Phase II mainly increased the Na^{+} and B^{+++} content in the species. Accumulation of B^{+++} (and other potential trace elements present in leachates from landfills) in the plants may be a risk to grazing animals, particularly accumulation in *Bromus hordaceous*, which has food value for sheep and wild animals.

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Table 6. Chemical analysis, number of leaves, dry weight and F values with their statistical degree of significance of *Hordeum murinum* and *Bromus hordaceus* plants on acid soil treated with deionized water and leachates in both experimental phases

Phases	Parameters	*Hordeum murinum* Deionized Water	Leachates	F(b)(c)	*Bromus hordaceus* Deionized water	Leachates	F(b)(c)
PHASE I	Watering on N	initial soil					
	(%)	2.50±0.90	1.90±0.40	0.37	2.45±0.25	2.25±0.15	0.40
	P (%)	0.60±0.13	0.50±0.04	0.57	0.40±0.05	0.37±0.00	0.21
	Ca^{++} (%)	0.95±0.05	0.95±0.05	0.00	1.30±0.10	1.13±0.08	1.96
	Mg^{++} (%)	0.24±0.04	0.33±0.04	2.53	0.31±0.05	0.38±0.01	2.65
	K^{+} (%)	4.30±0.50	4.40±0.40	0.02	3.75±1.15	4.00±0.20	0.05
	Na^{+} (%)	0.02±0.01	0.14±0.02	28.80*	0.09±0.04	0.26±0.08	3.77
	B^{+++} (ppm)	16.0±3.0	16.0±3.0	0.00	20.0±0.0	22.0±2.0	1.00
	Nº of leaves	5.7±1.9	7.3±2.9	1.3(b)	2.2±1.2	2.3±1.4	1.0(b)
	Dry weight	0.78±0.24	0.95±0.35	1.2(c)	0.82±0.31	0.91±0.46	1.1(c)
PHASE II	Watering on	treated soil (a)					
	N (%)	2.27±0.15	2.87±0.38	2.22	4.30±0.17	4.03±0.03	2.29
	P (%)	0.49±0.01	0.51±0.03	0.67	0.47±0.10	0.74±0.16	2.00
	Ca^{++} (%)	0.63±0.04	0.57±0.03	1.20	0.82±0.11	1.41±0.19	7.52F
	Mg^{++} (%)	0.26±0.01	0.29±0.01	11.00*	0.49±0.00	0.66±0.08	4.11
	K^{+} (%)	4.65±0.09	4.73±0.07	0.58	4.13±1.08	5.71±1.65	0.65
	Na^{+} (%)	0.68±0.04	1.20±0.12	18.01*	1.01±0.22	1.34±0.22	1.16
	B^{+++} (ppm)	44.0±10.4	1136.0±14.0	3918.28***	86.8±14.0	1152±497	4.60F
	Nº of leaves	2.2±0.9	1.8±0.8	0.8(b)	1.0±0.0	1.0±0.0	1.0(b)
	Dry weight	0.71±0.11	0.96±0.34	1.4(c)	0.50±0.17	0.37±0.11	0.7(c)

(a) Soils watered with leachate in Phase I and used again in Phase II. (b) (c)= dry weight or number of leaves quotients of the plants treated with leachate or watered with deionized water.
* $p<0.05$: (F at 95%: significant); ** $p<0.01$: (F at 99%: highly significant); *** $p<0.001$: (F at 99,9%: very highly significant); F = $p<0.09$

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